Mine Reclamation Using Biosolids

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Spreader fan distributing a mixture of biosolids and fly ash on the Palmerton, PA Site

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DEFINITIONS OF SELECTED TERMS AND ACRONYMS

Air slaking: The process of breaking up or sloughing when an indurated soil is exposed to air

Anhydride: A chemical compound formed from another, often an acid, by the removal of water

Caustic lime: Calcium hydrate or slacked lime; also, in a less technical sense, calcium oxide or quicklime

Fly ash: The very fine particle ash that results from the combustion of coal, and is mainly silica oxide and alumina oxide.

Inductively Coupled Plasma Spectrometer: Inductively coupled plasma is a high energy, optically thin excitation source. Power from a radio frequency generator is coupled to a flow of ionized argon gas inside a quartz tube encircled by an induction coil. Liquid samples, in the form of aerosols, are injected in to the high temperature environment caused by the plasma. The spectrometer analyzes form free atoms and ions that emit characteristic spectra, which allows for identification.

Line transect method: A marked cable, line, or tape measure is placed across the surface of a field for which an estimate of the percentage of ground cover is desired. Careful observation of the number of marks that occur above various types of ground residue and/or cover may be counted and extrapolated into an estimate of protective cover for the entire field. This is then used to predict the impact on soil erosion.

MSW: Municipal solid waste facility.

Oxidation: The loss of electrons from an atom, compound, or molecule. Generally, the term is applied to the chemical reaction of a substance with oxygen or an oxygen-containing material that adds oxygen atoms to the compound being oxidized.

POTW: Publicly owned treatment works.

FOREWORD

The purpose of this report is to describe the current uses of biosolids in the United States, especially the progress being made at mine reclamation sites. The background section will define and describe the production and traditional uses of biosolids. It will respond to common concerns over biosolid use, such as leaching, and explain the safeguards associated with every biosolids project. Finally, case studies will be examined and analyzed to determine the best use of biosolids to date.

Biosolids have proven effective in the reclamation and treatment of former mining sites. They are able to cost efficiently establish a vegetative cover on contaminated lands and limit the movement of metals through erosion, leaching, and wind. A cap is formed upon the application of biosolids because their permeability and water adsorption characteristics prevent water contact with contaminates in the soil below. Depending on the amendments added, biosolids can serve many purposes, including pH control, metal control, and fertilization. Their adaptability allows them to conform to the specific characteristics of any reclamation site.

Although biosolids limit the phytoavailability and bioavailability of toxic metals, they do not remove metal contaminants from the soil. Their application serves to control the mobility of heavy metals and various other contaminates, such as sulfates, through the soil. When combined with phytotechnologies, however, biosolids not only could contain contaminants, but also provide higher degrees of extraction than that offered by typical vegetative covers. Phytotechnologies use plants to contain, stabilize, reduce, detoxify, and degrade contaminants in soil, ground water, surface water, or sediments.

Phytotechnologies can be applied in situ or ex situ and can address organic compounds such as petroleum hydrocarbons, gas condensates, crude oil, chlorinated compounds, pesticides, and explosive compounds plus inorganics including high salinity, heavy metals, metalloids, and radioactive materials (U.S. EPA, 2001a). If biosolids and phytoremediation were used in tandem, they could possibility restore and return a site to near its original condition.

Even though the application of biosolids to remediate mining sites is considered an innovative technology, unlike many others, it can be used effectively and efficiently now. Biosolids technology is already available. It is just a matter of overcoming a few remaining obstacles before the technology can be fully utilized.

Biosolids reclamation use is expected to rise as public support increases and increasing amounts of biosolids are being produced. With increased production comes a greater need for disposal options. With tipping fees at landfills expected to increase and heightened regulations on incineration, land application is quickly becoming the most cost effective disposal method. The amount of biosolids estimated to be in beneficial use by 2010 is nearly 5.7 million dry tons. Many mining sites are still in need of some form of reclamation and biosolids are continually being tailor made for each of these sites.

Today, there is speculation as to how well biosolids perform and under what conditions they can be productive. Test sites such as Bunker Hill, Palmerton, Silesia, Leadville, along with other reclamation projects, will answer many questions regarding biosolids application to mining sites. Results from these sites are promising and biosolids use should only expand in the future.

1. Overview of Biosolids

Biosolids are the dark, organic, and nutrient-rich materials produced as a byproduct of current wastewater treatment practices. Since the enactment of the Clean Water Act in 1972, which required that all municipal wastewater be subjected to certain purification treatments, biosolid production has risen dramatically. From 1972 to 1998, biosolid generation grew nearly 50 percent from 4.6 million dry tons to 6.9 million dry tons (U.S. EPA, 1999). With heightened restrictions and limitations on biosolid content, disposal options are a continually growing concern of municipal solid waste (MSW) facilities.

After passage of the federal Marine Protection, Research and Sanctuaries Act (MPRSA), which banning ocean dumping of wastewater, the major disposal options for biosolid producers have been landfills, incineration, and land application. Initially, the use of landfills and incineration predominated because of cost considerations, and because these disposal methods require less advanced treatments. Concerns over contaminants such as heavy metals, organic chemicals, and pathogens were largely responsible for limiting the use of biosolids as a land application. However, site studies conducted during the past decade have revealed the regenerative qualities that land applied, amended biosolids possess. Researchers have been able to reclaim abandoned mining sites and provide once baron lands with self-sustaining and biologically active ecosystems.

Despite the benefits of biosolid application to the environment, their use is limited by a number of factors. Biosolids can only be applied to sites with the proper topographic properties because of concerns over water run-off and the potential for leaching. This means that a selected site cannot have geographic features, such as excessively steep slopes that would allow biosolid erosion in heavy rains or waterways in close proximity that could potentially become contaminated. Transportation and accessibility are other major contributing factors. For example, if a site is densely covered in trees or brush, application vehicles may not have access to the desired lands. For these reasons, biosolid land applications are best suited for semi-level terrain away from water sources but near roads to allow for easy vehicle access (Cogger, 2000).

Although biosolid use has been hindered in the past by misconceptions and strict regulations, industry, government, and the private sector are developing innovative ways to recycle biosolids. Biosolids have actually been sold commercially as fertilizers for several years under such names as Compro®, Bay State Fertilizer®, and Milorgamite®. Government agencies, such as the U.S. Environmental Protection Agency and U.S. Department of Agriculture, have taken advantage of biosolids' nutrient rich structure. Former mining sites, such as Bunker Hill in Idaho and Palmerton in Pennsylvania, have utilized biosolids to produce vegetative covers which control erosion and the spread of heavy metals (Bastian, 1997). The Bunker Hill Superfund site in the Coeur d'Alene River Basin is the second largest Superfund site in the nation. The mining and smelting of zinc-, lead-, cadmium-, and arsenic-rich ores from 1916 into the 1980s has resulted in the contamination of mountain soils. The Palmerton site was in operation from 1898 to 1980, and its two zinc smelters produced 33 million tons of contaminated residue. The details of these two Superfund sites will be discussed later in this report. There are many other biosolid operations currently underway across the nation including agricultural and forest applications.

2. Biosolid Treatment Options

With a constantly increasing population comes a larger amount of sewage sludge and waste products. Researchers have been given the challenge of developing innovative ways to deal with the increasing supply of biosolids. Depending on the degree of treatment undergone at the wastewater facility, the options for disposal can have a limited range. Each disposal option has specific requirements addressing concerns such as pathogen levels and heavy metal content. This section will focus on the treatment process sludge must undergo before it can be classified as a biosolid and be disposed of through land application, incineration, or landfilling. The main sources for this section include Bastian (1997), U.S. EPA (1995), and National Small Flows Clearinghouse (1998).

2.1 Sewage Sludge Treatment

There are four levels of treatment—screening, primary, secondary, and tertiary—used in wastewater management facilities. Each treatment produces a product with different chemical and physical characteristics. The method and degree of treatment determine the potential use of the biosolid.

2.1.1 Screening and Grit Removal

Screening removes coarse, larger solids that have the potential to interfere with mechanical treatment equipment. After screening, sludge is sent to a grit-removal system that filters out heavy, inorganic, sandy solids so that channels in the treatment apparatus are not interfered with and hindered. The solid produced as a byproduct of screening and grit removal is handled as a solid waste and does not classify as a biosolid under the regulation (40 CFR 503). Because this treatment only produces a more easily treatable sewage and does not effect bacterial contamination, its product is almost always landfilled.

2.1.2 Primary Treatment

Primary wastewater treatment removes the solids that settle out easily from the wastewater after screening and grit removal have been performed. It usually involves the use of gravity sedimentation to remove the suspended solids. Sedimentation is a process in which a suspension settles out of a fluid, leaving the upper portion less concentrated and the lower portion heavily concentrated in the settled substance. As a unit operation, sedimentation is inexpensive but somewhat inefficient, especially when dealing with particles with low settling rates such as biological materials. Despite its inadequacies, sedimentation is common in water and wastewater treatment facilities to collect inorganic precipitates and organic flocculent masses. The resultant biosolids of primary treatment contain anywhere from 93 to 99.5 percent water along with small amounts of solids and other dissolved substances. Usually, thickening or dewatering can reduce the water content of primary biosolids.

2.1.3 Secondary Treatment

Secondary wastewater treatment generally involves a primary clarification process followed by a biologic treatment and secondary clarification (U.S. EPA, 1990). During the biological treatment process microorganisms are used to reduce oxygen demand and remove remaining solids. Biosolids produced by secondary treatment tend to have a low solids content of around 0.5 to 2 percent and are not as easily thickened or dewatered as primary biosolids. Secondary treatment is the minimum allowable treatment level for publicly owned treatment works (POTWs) under the Clean Water Act of 1972.

2.1.4 Tertiary Treatment

Advanced wastewater treatment processes, such as chemical and biological precipitation, produce tertiary biosolids. During tertiary wastewater treatment, metal content is of the greatest concern, especially with regard to nitrogen and phosphorus. The chemicals used in this treatment (aluminum, iron, salts, lime, and organic polymers) increase the mass and volume of the biosolid product. The water-absorbing characteristics of the resultant biosolid depend on the chemicals used. For example, if lime or organic polymers are used, the dewatering and thickening ability of the biosolid will improve, whereas use of iron will produce a biosolid with less dewatering and thickening capabilities. Tertiary treatment is used mainly by POTWs that demand higher effluent quality for use in projects such as land application and remediation that may involve human contact.

2.2 Stabilization and Dewatering

Once biosolids have undergone initial treatment, they also must have additional treatment before they are disposed of to comply with regulations, help handling, and reduce costs. Only those biosolids that have been through a second treatment process and comply with federal, state, and local regulations can be transported for disposal. After completing a treatment process the physical properties of the biosolids are changed. They usually become a dry solid rather than slurry, and their volume may be increased or decreased depending on the type of treatment applied. Biosolids in dry form are much easier to transport and transportation also becomes more cost efficient. Stabilization and dewatering are the most prevalent forms of treatment at this time. The different methods of stabilization and dewatering are listed in Table 1.

Table 1. Biosolid Treatments and Uses

Treatment Process	Application or Disposal
Alkaline Stabilization	High pH of alkali-stabilized biosolids immobilizes heavy metals. Biosolids produced useful for various land applications and daily landfill cover.
Aerobic and Anaerobic Digestion	Greatly reduces biosolid mass and volume. Produces biosolids used as soil amendments and fertilizers on forests and reclamation projects.
Composting	Excellent soil conditioning properties although may contain less nutrients than less processed biosolids.
Heat Drying	Reduces volume of sewage sludge. Produces fertilizers used at lower rates because of nitrogen content.
Dewatering	Reduces land requirements and transportation costs. Allows for incineration and other treatment options.

Source: EPA, 1999

2.2.1 Alkaline Stabilization

This form of treatment stabilizes the sludge treated through the addition of an alkali. The most common alkali is lime; however, kiln dust, Portland cement, and fly ash also have been used. Application of alkali raises sewage sludge pH to decrease biological activity and reduce pathogen levels. Since the effects are temporary, odor and leacheate generation may return over time.

2.2.2 Anaerobic and Aerobic Digestion

Both anaerobic and aerobic processes stabilize sludge through biological conversion of organic matter to compounds such as water, carbon dioxide, and methane. Anaerobic digestion takes place in a closed container devoid of oxygen, in which anaerobic bacteria break down the organic components of the sludge. Aerobic digestion undergoes the same process but involves oxygen-loving bacteria. These processes reduce pathogen content and odor while resulting in a product with less mass and higher solids content.

2.2.3 Composting

Composting is an aerobic, biological process that stabilizes sludge using a windrow, aerated static pile, or vessel. Biosolids are decomposed to a humus-like material with a pH between 6.5 and 8.0, which provides excellent growing conditions. The process destroys most pathogens and increases the mass due to bulking agents.

2.2.4 Heat Drying

This process uses the application of heat to kill pathogens and eliminate water content. Solar drying is used in some locations; however, active and passive dryers are more common. Heat drying slightly lowers potential for odor but greatly reduces volume.

2.2.5 Dewatering

Dewatering is a high-force separation of water from solids that decreases the volume of biosolids. Transportation costs to land application sites are drastically lowered because of the lesser volume. Dewatering is also required before incineration to protect boilers and decrease energy required for combustion. The most common dewatering methods are vacuum filters, lagoons, centrifuges, sand drying beds, and filter presses.

3. Biosolid Disposal Methods

Once sewage sludge has been processed in a waste treatment plant, a viable disposal option must be found. As environmental quality standards and sewage sludge production increase simultaneously, municipal treatment plants are having a more difficult time finding the proper sites for disposal. With the virtual elimination of ocean dumping the main options available today are landfills, incineration, and land application. In this section advantages and disadvantages of each of these three options will be discussed with respect to the environment, humans, and cost. The main sources for this section include Sopper (1993), U.S. EPA (1999), and Bastian (1997).

3.1 Landfill and Surface Disposal

Landfill and surface disposal make up about 17 percent of the total application of biosolids today (U.S. EPA, 1999). The use of landfills reduces treatment costs for many municipal wastewater treatment facilities because landfilled biosolids require less advanced treatments. Federal and state regulations do not require many of the stabilization and dewatering methods for landfilled biosolids. Landfilled biosolids also require no additional monitoring for leachates and metal content that land application sites would. This is why for many years landfills were the most available and plausible disposal option for increasing amounts of biosolids. However, bans on disposal of biosolids in landfills, landfill capacity concerns, and landfill closures have greatly hindered the use of landfills as a profitable disposal option. Limited space means higher tipping fees and a greater cost to the wastewater facility trying to dispose of its biosolids inventory. Table 2 summarizes the pros and cons of disposing of biosolids in landfills.

Surface disposal is another option to be considered by a municipal wastewater facility. The Biosolids Rule (40 CFR 503), defines surface disposal as the placement of biosolids for final disposal on land on which only biosolids are present. Under this rule, the biosolids must remain untouched on the land for a least two years to be considered disposed; otherwise, it is classified as storage or treatment.

Site selection for biosolid surface disposal is based on factors such as land slope, soil conditions, and required minimum proximity to ground or surface water. Human and animal contact also weigh in heavily when trying to select an appropriate site. The main difference between surface and land disposal is application rate. Surface disposal simply means that the biosolids have been applied at levels greater than agronomic rates and require a form of leachate monitoring such as underground wells.

The most common form of surface disposal is depositing biosolids in monofills. Monofills come in various forms including excavated trenches, large excavated areas, mounds, and layers on the ground covered with topsoil. Upon completion all monofills are covered with several centimeters of soil to prevent odor and reduce human and animal contact.

Table 2. Advantages and Disadvantages of Landfills

Advantages	*Disadvantages*
Once disposed of in a landfill there are no additional costs for monitoring and no concern over human contact	Does not utilize the nitrogen and nutrient rich qualities of the biosolids
Leachates are contained safely inside the landfill's liner	Landfill space has become extremely limited in recent years and biosolids take up space when they could be used beneficially in the environment
Public concern and outcry is avoided	Involves a large initial contracting cost for transportation and tipping fees

3.2 Incineration

Biosolids incineration requires extremely high temperatures (450°C and higher), which are provided by specialized furnaces. The two most common types are multiple-hearth furnaces and fluidized-bed furnaces; however, the latter (Figure 1) is preferred because in general it produces fewer emissions.

In order to prevent dangerous gases, particles, and other pollutants from escaping into the environment, these furnaces are equipped with air pollution devices. The most common emission controllers include wet scrubbers, fabric filters, afterburners, and precipitators. After incineration, only about 20 percent of the biosolid volume remains, and many of the volatile organic chemicals and pathogens are eradicated.

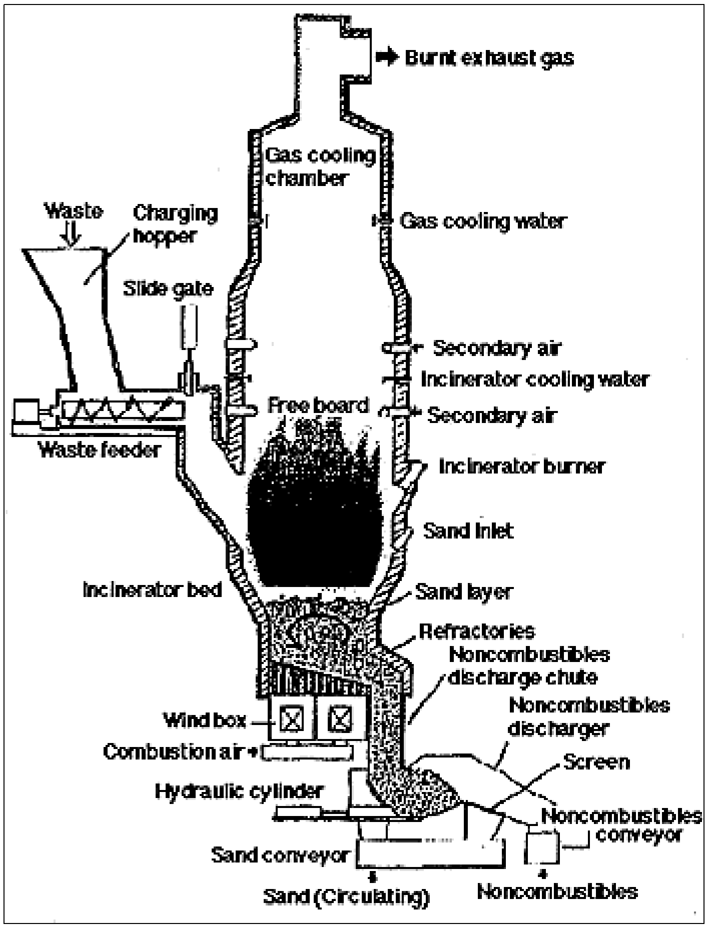

Figure 1 – Mitsubishi Fluidized Bed Incinerator
Source: GEC, 2001.

Table 3. Advantages and Disadvantages of Incineration

Advantages	*Disadvantages*
Reduces volume of biosolids allowing easier disposal	Dewatering is required before beginning the incineration process because water content increases the energy necessary
Energy can be collected from the incineration process	Pollution devices must be installed to capture emissions
Destroys virtually all of the pathogens and VOCs present	The ash produced has large heavy metal concentrations
Requires little land area for operation relative to landfilling and dewatering	High energy requirements and costs

3.3 Land Application

A growing alternative to traditional waste disposal is the land application of biosolids. Because biosolids contain many nutrients and metals necessary for plant life, they are able to serve as fertilizers and as a reclamation option. Land application is a good and logical disposal option because not only does it dispose of the materials but it also puts them to beneficial use in the environment.

3.3.1 Title 40 of the *Code of Federal Regulations,* Part 503 Rule

There are several provisions listed in the Part 503 regulation that must be taken into account during any land application operation. It states that biosolids cannot be applied to flooded, frozen, or snow-covered land under any circumstance because of concerns for metal contamination in runoff. Biosolids also cannot be applied to forests, public contact sites, or reclamation sites in ways that allow them to enter wetlands or other waters except under permit. The 503 rule provides requirements for minimum distances (Table 4) that biosolids can be applied from geographic features, such as waterways and roads.

Under Part 503, biosolids may not be applied to land if it is likely to adversely affect a threatened or endangered species listed under Section 4 of the Endangered Species Act or the designated critical habitat of such a species (Title 40 of the *Code of Federal Regulations* [CFR], Part 503 Rule). Critical habitat is land that an endangered or threatened species depends on during its life. Applying harmful amounts of biosolids to one of these areas is seen as destruction and classified as adverse modification.

When applying biosolids to land, not only does the part 503 rule have to be taken into account but also any state or local regulations. Depending on the state the land application requirements vary with some being even more stringent than the federal regulations.

Table 4. Typical Buffer Zones

Contact	**Required Distance**	
	Feet	*Meters*
Public road	0-50	0-15
House	20-500	6-152
Well	100-500	30-152
Surface water	25-300	8-91
Property line	none-100	none-30
Intermittent stream	10-200	3-61

Source: Basta (1995), p. 401

3.3.2 Site Selection

The most useful initial sources of information for determining site suitability for land application are soil surveys. They provide detailed soil maps as well as data on the drainage and agronomic properties of the soils on a potential application site. Agricultural professionals use soil surveys frequently to identify sites that meet regulatory and agronomic requirements for the land application of biosolids. Once appropriate sites are found using these surveys the next step is to examine them in even greater detail.

3.3.2.1 Topography

Topography is a graphic representation of the surface features of a place or region on a map, indicating their relative positions and elevations. It is vital to examine a potential site's topography because it affects the surface and subsurface water flow, which affects the amount of erosion and runoff that may occur. Because biosolids may contain metals, it is essential that they not enter the water supply too rapidly and cause contamination. This is why limits have been enacted on the steepness, length, and shape of slopes to which biosolids may be applied. As shown in Table 5, the limits on permitable land slope vary depending on the type of biosolid application being used.

Table 5. Slope Limitations for Biosolid Application

Slope	Application Type Permitted
0-3%	Ideal; any application with no concern for runoff
3-6%	Surface application acceptable with slight risk for erosion
6-12%	Injection of liquid biosolids required in most cases. Surface application of dewatered biosolids acceptable
12-15%	No liquid biosolids except with runoff control. Surface application with dewatered only with immediate incorporation
Over 15%	Only sites with good permeability in which the slope is a minor part of the entire site

Source: U.S. EPA (1995), Table 5-8

Quadrangle maps published United States Geological Survey are helpful for preliminary work. However, because of their scale, they cannot be relied on alone to provide a completely accurate representation of a site. Field investigation is still necessary to determine the true characteristics of potential sites and application rates of biosolids.

3.3.2.2 Soil Characteristics

Since complete soil characteristics cannot be represented for areas smaller than 0.8 to 1.2 hectares (2-3 acres) by the Soil Conservation Service mapping, there is the possibility that soils with very different characteristics can be left unidentified on a site. This is very significant because application rates depend on soil properties such as infiltration and permeability. If the differences on site are significant, the application rates must be adjusted.

The texture of the soil and geologic material is an important aspect of selection because of the influences it has on drainage, infiltration, and permeability. Fine textured soils tend to have low permeability, which means that water and air pass through the soil slowly. On the other hand, coarse soils tend to be highly permeable because of pore space and distribution, so water and air pass through them very rapidly. Soils with low permeability are best because they prevent events such as erosion from occurring by absorbing water and holding it within their structure. This means that the water will pass through the soil rather than flowing beneath it or over its surface, which increase the possibility for erosion. The application rate of biosolids depends greatly on the permeability of the soil to which it is going to be applied. In general, a more permeable soil means a greater rate of biosolids application.

3.3.2.3 Climate

Climate is a very important factor in the preliminary planning phase for biosolid application. Rainfall, temperature, and wind are important climatic factors that can affect the rate of application. Depending on the climate in which the biosolids are applied, operation time and cost, leaching potential, and runoff potential can be increased. For example, an area with heavy rainfall provides greater opportunity for enough water to pass beneath biosolids to carry them down gradient. More water in the soil also creates more pathways for metals to leach to ground water.

3.3.2.4 Human Contact

For safety purposes, there are often certain times when no access is allowed to application sites. These time limits vary depending on the type of treatment the biosolid mixture has received. The main reason for these precautions is the fear of metal exposure, which diminishes as the metals become incorporated in the soil.

4. Biosolid Design

Biosolids can be termed "designer" composts because they are custom made to satisfy the nutrient requirements of the site to which they are applied. Because each site has unique soil and geographic characteristics, biosolids are formulated and amended to provide a suitable cover. Biosolids must restore and reclaim land without having negative effects on any other part of the environment.

4.1 Correcting pH

At sites appropriate for reclamation, soil pH is often a main contributor to the sparseness of vegetation in the area. The soil has usually become so acidic that no form of flora has the ability to grow. The biosolids are applied in order to promote plant growth through their rich nutrients; however, many biosolids are acidic themselves and must be stabilized with amendments to allow for vegetation to occur. The most common amendments include lime, other residuals with a high calcium carbonate equivalent (CCE), and fly ash. Because of their alkalinity these amendments have the ability to raise the pH of the surrounding soils and produce an environment that promotes vegetative growth.

4.1.1 Lime

Combining biosolids with residual lime can result in an excellent soil treatment for disturbed soils. Limestone and other CCEs are the most common type of material to blend with biosolids. Only lime-based alkaline earth metals should be used, because they form insoluble compounds that protect ground water and wildlife. If alkaline materials are used, they can react with the biosolids to create high levels of sodium and potassium salts. These salts pollute the leachate produced when high levels of water enter the soil, and they cause significant damage to the environment because they are toxic to most plant life. As long as the proper form of lime is used and application rates do not exceed the buffering capacity of the soils, the pH will not exceed 7. Excessive rates, however, will lead to contamination and high toxicity.

In order to determine application rates, laboratory tests must be performed on samples with the same concentrations of biosolids and amendments that are to be used in the full-scale project. The laboratory tests serve only to create a basis line for application rates because when experimental concentrations are applied full-scale some discrepancies will arise. The samples used in testing are only very small portions of a site's land area; hence, they do not account for variations in soil content over the entire range of the site. Adjustments must be made on site after application in order to achieve optimum remediation capability.

Limestone initially increases the pH of acid spoils, but the pH eventually declines primarily as sulfur-bearing minerals are oxidized (Sutton and Vimmerstedt, 1974). "To oxidize" is synonymous with "to acidify" because in nearly all cases the more oxygen a substance contains the more acidic qualities it exhibits. Thus, by oxidation the sulfur present in the limestone amendment passes into compounds called *acid anhydrides* and enters into an acidic state (SO_4 and H_2SO_4) decreasing the overall pH of the soil.

In order to sustain the proper pH levels in treated soils, slower reacting limes may be preferable. Slow reacting limes are generally classified as agricultural limes, which include calcium carbonate ($CaCO_3$), burnt or slaked lime (CaO, CaOH), and dolomitic limestone. They have an initial pH of about 8.3 compared to a pH of 10 in faster reacting limes; however, as a result of their slower reaction rate their pH levels are held more constant than faster reacting, higher pH limes. For example, in a zinc smelting area, biosolids treated with lime raised soil pH from 5.8 to 6.5 within in two years of application (Brown, 2000).

As reported by Pietz (1989), results of coal refuse samples (0-15 cm) analyzed over a five-year period, show lower concentrations of water-soluble aluminum and iron (Table 6).

Table 6. Concentration of Water-Soluble Al and Fe in Biosolids – Amended Soils

Year	Control Al (mg/kg)	Biosolids/Lime Application Al (mg/kg)	Control Fe (mg/kg)	Biosolids/Lime Application Fe (mg/kg)
1976	279	9	233	8
1978	255	3	190	1
1979	136	39	119	4
1980	103	2	68	1
1981	105	2	31	Less than 1

Source: Pietz, 1989

The lower concentrations reflect the biosolids' ability to retain the aluminum and iron while the lime was able to decrease solubility through increased pH and resulted in the precipitation of the two metals. The metals were most likely retained due to precipitation as carbonates, sulfides, oxides, silicates, or phosphates and absorption by organic matter.

Lime is very valuable when designing an application for the specific characteristics of a site. When applied in the proper proportions, it has the ability to balance pH and promote reclamation.

4.1.2 Fly Ash

Fly ash has been used as a soil amendment for increased water retention and the prevention of biosolid erosion. The combustion of wood waste and coal for production of steam or electricity creates vast localized sources of fly ash. Ash composition varies with the source of the waste wood or coal being burned. One study found that pine sawdust ash had a pH of about 13, and that the ash contained 18 to 26 percent calcium, 6 to 9 percent magnesium, 0.4 to 11 percent potassium, and 1.7 to 2.5 percent phosphorus. The study found that the temperature at which the waste was burn influenced the composition of the ash. Another study using hardwood ash found a composition of about 6 percent potash, 2 percent phosphoric acid, and 30 percent lime (Hoffman 2001). Because of its relatively high pH fly ash has become a very valuable amendment option. Nearly 6,350 metric tons of fly ash produced from coal alone are used per year for mine reclamation (Figure 2).

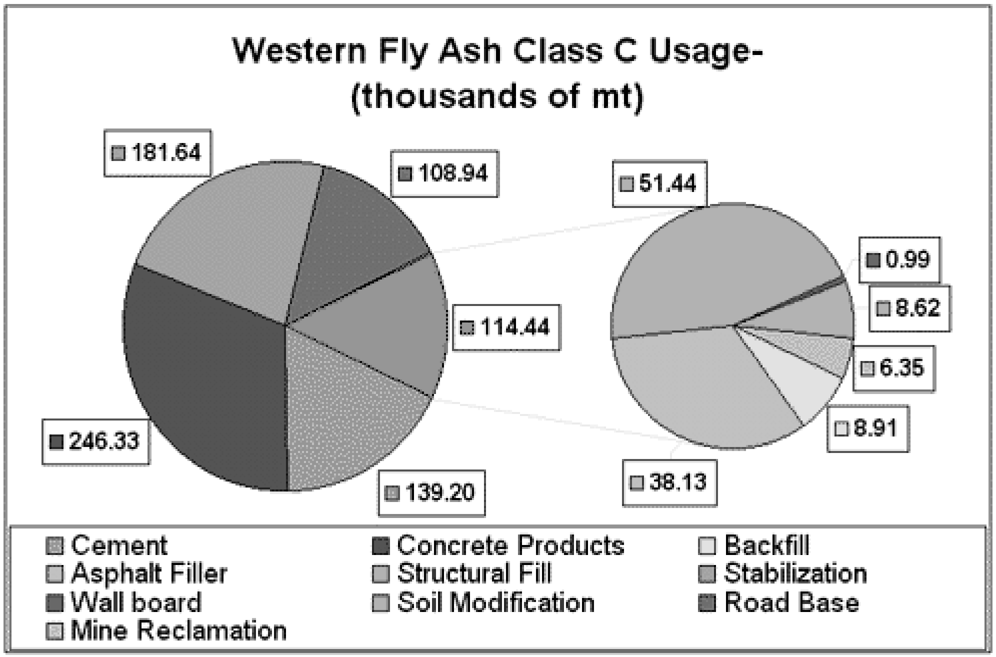

Figure 2 – Fly ash use and disposal

Source: Hoffman, 2001

When blended with biosolids, fly ash provides the biosolids with a cement-like hold to the ground because of its dense composition. Consisting mostly of silica, alumina and iron, fly ash is a *pozzolan*—a substance containing aluminous and silicious material that forms cement in the presence of water. When mixed with lime and water it forms a compound similar to Portland cement. When used in the proper proportions, the cement-like properties are ideal for binding biosolids to the land. Fly ash also contains many metals, such as calcium and magnesium, that promote plant growth.

Fly ash and other industrial wastes and co-products are suited for application to sites only if they consist of a sufficient amount of free lime and are reactive with water. Free lime is defined as lime that is not chemically bound with other compounds. Only free lime can react unrestricted with water to form the hydroxide ions, heat, and high pH levels needed for soil stabilization (Francis, 1998). Stabilization problems arise when fly ash with low reactive limes is blended with biosolids because lack of water absorption prevents reactions that result in desired pH levels. Hard burning, water insoluble coatings, and air slaking are the major causes of low reactive limes in fly ash.

4.2 Leachates

Biosolids have been shown to improve the capacity of spoil material to support vegetation; however, concerns arise over metal movement through the soil and into waterways. Effects of metals on sites vary depending on loading rates, biosolid quality, and the form of the metals. Some metals regulated by the U.S. EPA include arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc. In order to prevent leaching, residuals must meet certain concentration levels for the above metals, as shown in Table 7.

Table 7. Metal Concentrations for Residuals

Metal	As	Cd	Cr	Cu	Pb	Hg	Ni	Se	Zn
Concentration mg/kg	41	39	1200	1500	300	17	420	36	2800

Source: 40 CFR 503

4.2.1 Nitrogen Control

When biosolids are applied to land, there is the potential for nitrate buildup that could eventually lead to leaching into ground water. The EPA nitrate limit for drinking water is 10 mg/L. Often after biosolids applications, nitrate levels will increase slightly in monitoring wells. The concentration levels will sometimes peak but then drop below the limit thereafter. Nitrogen levels tend to peak in late winter and spring when site vegetation is not using soil nutrients for growth. Despite heightened initial levels measured when land-applying biosolids, application does not seem to affect ground-water concentrations of nitrate-N.

4.2.1.1 Monitoring

Monitoring biosolids sites focuses mainly on the metal concentrations and nutrient levels in soil and water. Monitoring typically includes up-gradient and down-gradient wells to test water content and soil sampling. Water samples may be analyzed for pH and nitrate-N using an ion-selective electrode. Dissolved metals are also measured using atomic absorption spectrometry. Soil samples are taken at several different levels below the surface (usually down to 30 cm) to test for leaching of metals and nitrogen. Several test methods can be used including atomic absorption..

4.2.1.2 Carbon and Nitrogen Balancing

Carbon and nitrogen balancing is a procedure that reduces potential nitrate loss from land reclamation sites. It provides enough organic matter to produce productive soil without excess nitrate leaching into the water table. Carbon and nitrogen balancing is the combination of carbon-rich, nitrogen-deficient amendment with nitrogen-rich biosolids. Under ideal conditions microbes will break down the carbon-rich amendment and biosolids simultaneously. The microbes should use the biosolids' nitrogen to balance nutrient needs and create stable organic matter. If the method is applied properly, it allows applications of organic matter without concern for exceeding the site's ability to assimilate nitrogen.

Carbon and nitrogen balancing requires the right type of carbon source for the given soil conditions. If the carbon source contains too much nitrogen, it will not immobilize the biosolids' nitrogen, causing nitrate loss and eventually even leaching. However, if the carbon source is too difficult for the microorganisms to break down, the biosolids will break down much more rapidly than the carbon source. The result of this action would be a short-term excess of nitrogen but a deficiency of nitrogen as time passed. The most effective carbon sources used to date are hardwood leaves, woody yard debris, straw, compost, and paper mill fines.

A typical mine reclamation project would require an application rate of 10 to 25 dry tons of biosolids and 100 to 150 dry tons of carbon source per acre. The application amounts vary depending on site characteristics such as topography and climate as well as the types of biosolids, carbon sources, soils, and depths used on site. Rates of application are by no means standard and each site has an unique application rate (Cogger, 2000).

When biosolids are used to reclaim, rates higher than agronomic applications are often used. Many times excess nitrogen is added to the soil creating a one-time increase in the nitrogen concentration of waterways. A residual with a relatively high carbon to nitrogen ratio can be added to offset this. When added to biosolids, a material with a high carbon to nitrogen ratio (40:1) will create excess carbon and immobilize the nitrogen (Brown, 2001).

4.2.2 Phytoavailability

Phytoavailability is defined as the ability of plants to uptake metals present in the soil. Biosolids tend to make harmful metals unavailable to plants through chemical pathways. This prevents the plants from experiencing stunted growth and germination problems caused by excess metals.

Exactly how biosolids reduce phytoavailability has been under question for many years. The "time bomb hypothesis" said that as the organic material in the biosolids deteriorated its metal holding ability would be lost releasing large amounts of metals into the surrounding soil. This view called into question many of the regulations set forth by the Part 503 rules, saying that results were based on data taken too soon after the application date. The following section will discuss this in greater detail with relation to a cadmium availability study.

4.2.2.1 Cadmium Availability

Elevated levels of cadmium in soil brought about by biosolids application have been thought an environmental danger. Many researchers have examined the phytoavailability of metals added to biosolids before and after digestion. A consensus has been reached that metals added before digestion are much less phytoavailable. This is because metals already present in biosolids upon application are less available to plant life. A chemical process occurs in which benign components of the biosolids mixture surround contaminants and prevent plants from absorbing them. Even when the bound metals enter a plant system, they remain bound and are not phytoavailable.

An onsite study was conducted by Brown, Ryan, Angle, and Chaney (1998) to measure the phytoavailability of cadmium in long term biosolids-amended plots. They tested cadmium uptake using lettuce grown on control and biosolid-amended plots. Many of the plots containing biosolids had the same cadmium levels as control plots. The results of the study indicate that the phytoavailability of cadmium added with biosolids application does not increase over time as the biosolids' organic carbon decomposes. This is in direct opposition to the time bomb hypothesis which states that as the organic carbon in the biosolids breaks down many heavy metal contaminates are released because of diminished metal holding capacity (Beckett, 1979).

Once biosolid soil pH was equivalent to the control and the organic matter content of the biosolids was less than or equal to that of the control, it could be concluded that the organic carbon present in the biosolids had decomposed. When lettuce cadmium concentrations of the decomposed biosolids and control plants were compared, there were identifiable differences. The results indicate that the organic carbon of the biosolids is not the major factor in decreasing cadmium phytoavailability. Instead the inorganic biosolid components seem to be responsible for decreased phytoavailability since the limitation of plant-available cadmium continued after the organic fraction had been removed.

This study did not include measurement of biosolid inorganic complexing levels, but others have. The basis of heavy metal absorption in biosolids are oxide surfaces. An oxide is any compound of oxygen containing another element or a radical. The oxides react with the metals present in the soil to form compounds that limit the availability of the metals.

4.2.3 Bioavailability

Researchers have increasingly looked toward limiting bioavailability as a medium to control large concentrations of metals at contaminated sites. Treatment focused toward bioavailability eliminates the need and cost of removing metals from the sites at which they are present. This reduces cost and requires less risk by workers because exposure to high concentrations of metals would be limited.

Bioavailability is the amount of metals readily available for animal ingestion or exposure. Biosolids are an excellent tool for limiting bioavailability because they cover the surface of a contaminated site while working chemically to bind metals within their structure. Even if animals should ingest soil containing toxic metals, the metals would pass through their system without any effect because metals are bound inside compounds and are not available for adsorption.

4.3 Acid Mine Drainage

Biosolids can also be used to treat acid mine drainage from abandoned mines. Acid mine drainage occurs when water and air come in contact with certain minerals found in mines. The sulfate-oxidizing *Thiobacillus* ferrooxidans bacteria catalyzes a reaction between the iron-sulfide minerals, water, and oxygen to form sulfuric acid, which solubilizes metals, leaves deposits, seeps into soil and ground water, and runs off into rivers (Sajjad, 1998).

Because of the inadequacy of conventional treatment methods, such as the addition of lime which precipitates contaminates as hydroxides, a biosolids-based technology is being investigated. The technology stimulates the growth of sulfate-reducing bacteria (SRB) in acid-generating mine wastes by introducing microbes that convert sulfuric acid to metal sulfides (Sajjad, 1998). This eliminates acidity (raises pH) and precipitates metals from the drainage. Metal sulfides typically have very low solubility in water with solubility products (K_{sp}) around that of Cu(II) sulfide, which is only 8×10^{-37}.

Separation of metals from acid mine drainage can serve several useful purposes including prevention of inhibitory effects of metals on SRB, recovery and recycling of valuable metals, and preventing toxicity in the environment. The key to commercialization of this technology is the availability of effective, low cost, and reusable biosorbent. Biosolids fit this description because they are easily accessed and have the proper chemical composition. Studies have shown their ability to effectively treat acid mine drainage.

5. Case Studies

This section will discuss the methods underway to reclaim and remediate several different mining sites. Each site has unique challenges and characteristics that require special remedial design considerations and adaptations. The sites have implemented varying treatments but all have seen significant improvement.

5.1 Bunker Hill

The Bunker Hill site, the second largest Superfund site in the nation, is located in Idaho's Coeur d'Alene River Basin. It comprises well over 600 ha and was entered on the Superfund National Priorities List in 1983. Mining and smelting were performed in the area for more than 60 years leaving extremely high metal concentrations in the surrounding soil. The metals mined include lead, zinc, cadmium, and arsenic which pose significant danger to the environment at the levels present. As a result of these metal deposits the site has low pH levels, a high susceptibility to erosion, low microbial growth, and diminished water holding capacity.

Early restoration efforts involved the construction of terraces on slopes exceeding 50 percent, application of limestone, and application of fertilizers proved unable to establish vegetation. For the past few years experts from the U.S. Department of Agriculture, University of Washington, University of Idaho, the Northwest Biosolids Management Association, Washington Water Power, and EPA have begun restoration efforts using biosolids along with other amendments. They hope to reestablish a vegetative cover and reduce current metal levels.

5.1.1 Goals

The main goal at Bunker Hill is to produce a stable, self-sustaining, and healthy ecosystem. In order for this to occur the following must happen:

- Reduction of erosion;
- Surface metal containment (i.e. tailings);
- A decrease in metal phytoavailability;
- Production of a self-sustaining plant cover;
- Development of efficient and cost effective remediation techniques; and
- Determination of viable combinations of residuals such as biosolids, fly ash, and log yard waste.

5.1.2 Site Application and Monitoring

The high concentration of metals present at Bunker Hill proved too high for traditional treatments, so a plan was designed involving biosolids. In order to determine the effects biosolid application would have on the site, demonstration and pilot-scale plots were installed in 1997. Local sources were used exclusively for application materials because of transportation limitations and cost effectiveness.

Biosolids provided by three different municipal facilities were blended in a one-to-one by volume ratio with wood ash from local power generators and log yard wood waste from a nearby railroad company. The first set of field plots, installed in June 1997, were large-scale treatment plots measuring thirty-three by thirty-three meters. They were created in a completely randomized design with three replicates. In October of the same year a second set of plots was installed (1 x 4 m) in area almost absent of organic matter.

The amendments for the first series of plots consisted of high nitrogen (4.4 to 5.3 percent) and low nitrogen (2.8 percent) biosolids applied at 55 and 110 mg/ha dry weight. All biosolids used in the test plots met 40 CFR 503 standards. The low nitrogen biosolids were stabilized in a lagoon making them more stable than the high nitrogen biosolids that were produced through anaerobic digestion. The specifications and content of the biosolid amendments can be seen in Table 8.

Table 8. Characteristics of Amendments Used in June 1997

Amendment Application	Zn (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	pH	C (%)	N (%)	Solids (%)	Depth (cm)
Low N								
56 mg/ha	1800±400	6.1±0.7	270±100	8.4±0.4	17±2	0.5±0.1	60±5	4.1±2.5
112 mg/ha	1100±200	9.0±0.6	220±20	7.6±0.1	20±2	1.1±0.2	49±7	6.1±2.3
High N								
56 mg/ha	1200±400	2.7±0.1	100±20	8.7±0.2	19±3	1.0±0.2	45±3	4.6±1.8
112 mg/ha	900±100	2.7±0.1	230±30	8.5±0.1	21±4	1.8±0.6	37±3	8.1±2.3
High N w/ Log Yard								
112 mg/ha	550±20	2.6±0.1	170±30	8.4±0.1	24±1	2.2±0.3	30±4	5.8±1.8

Source: Brown *et al.*, 2000

For these plots no incorporation of biosolids was performed. The amendments were simply spread over the surface after being mixed immediately prior to application. The biosolids were mixed with 220 wet mg per ha of wood ash to act as a 55 mg/ha calcium carbonate replacement. log yard waste was also mixed at 20 percent by volume with two of the high nitrogen biosolids and all of the low nitrogen biosolids to increase the carbon to nitrogen ratio and limit nutrient runoff. Also of note, one of the high nitrogen biosolids was applied at 112 mg/ha without being blended with the log yard waste amendment.

The second set of plots was focused on testing a wider range of amendments that included pulp, paper sludge, and compost. Some of the plots contained more traditional land treatments including Glacier Gold compost. Several different combinations of amendments were tested including biosolids with pulp fines and with and without ash (Brown *et al.*, 2000).

Prior to application a native seed mix was scattered on the surface of the biosolid amendments. Reseeding was necessary on the high nitrogen biosolid plots because there was sufficient ammonia volatization to kill the seeds included in the amendment originally. The reseeding was successful and established a vegetative cover in the first growing season. After further investigation at the site, it was determined that waiting a period of 48 hours before seeding and the use of less caustic lime will avoid germination failure.

Plant sampling for elemental analysis was performed in August 1997, July 1998, and June 1999 on the first set of plots. The dates of sampling for the second set of plots are identical except that no samples were taken in August 1997. A complete sample included at least three subsamples collected from each of the test plots. All samples consisted only of grass. Once the samples were collected they were washed in deionized and distilled water for purity. Samples were turned into ash at 480° C then digested in concentrated HNO_3 and finally analyzed with a flame atomic adsorption spectrometer or inductively coupled plasma spectrometer. In this study percent cover was measured in 1998 using the line transect method. Three measures were taken on each plot with each being seventeen meters in length. Vegetation was classified as plants within a 20 cm proximity of each other. For samples taken in 1998 and 1999 biomass measurements were also collected in three areas by using a circular sampling area of 615 cm^2.

Soil samples were also taken on each of the first and second set of plots. The soil samples were taken along the horizon to a depth of 15 cm below the amended lands. Once gathered, the samples were analyzed for pH, carbon, nitrogen, and metal content. The pH and zinc levels from the first set of plots are given below (Table 9).

Table 9. pH and Zinc Levels in 1st Plot Set

Application	pH level	Extractable zinc (mg/kg)
Control	5.8±0.9	150±60
Low N 110 mg/kg		
Amendment Soil	7.1±0.5 5.9±1.0	1.9±0.3 87±60
Low N 55 mg/kg		
Amendment Soil	7.8±0.1 7.3±0.4	0.8±0.1 11±1
High N3* 110 mg/kg		
Amendment Soil	7.4±0.1 7.6±0.2	1.0±0.1 12±2
High N 110 mg/kg		
Amendment Soil	7.3±0.3 7.0±0.6	1.0±0.1 14±6
High N 55 mg/kg		
Amendment Soil	7.8±0.2 7.5±0.5	1.7±0.6 9±2

*Applied without log yard waste
Source: Brown *et al.* (2000), Table 3

It is apparent from the results there was a reduction in extractable zinc and an increase in pH. This indicates that alkalinity added through the lime-containing amendments was somewhat mobile through the soil. In both the first and second plot sets roots were observed penetrating into the subsoil, which may be the result of lower levels of phytoavailable metals. It also appears, from the results, that the high nitrogen biosolids amendments are more effective at transferring alkalinity through the soil. Log yard waste seems to have had no effect on pH levels or metal concentrations.

Sampling of the second set of plots revealed significantly lower levels of extractable zinc than control and conventional treatments. The plots also produced a much larger quantity of biomass than control and convention treatments. Again the high nitrogen amended biosolids proved the most effective.

The carbon-to-nitrogen ratio is a very good indicator of a healthy soil. A ratio of 20:1 is characteristic of a well functioning soil system. Any ratio below this indicates an excess of nitrogen in the soil system. As plants grow and begin depositing matter on the soil the carbon-to-nitrogen ratio will increase. However, if the ratio becomes greater than 25:1 then there is not sufficiently active soil for decomposition and plant nutrients will not be recycled. All of the high and low biosolids treatments have ratios within those defined as healthy. Once again log yard waste seemed to have no impact on the results. The only concern, as far as the carbon-to-nitrogen ratio, occurred in low nitrogen treatments where the ratios were increasing or remaining relatively high indicating that there was not enough nutrient recycling in the system to maintain vegetation.

5.1.3 Performance

The low nitrogen biosolids produced germination of a gamut of native grasses and legumes. Unfortunately, the ammonia toxicity present in the high nitrogen biosolids killed all seedlings present in the native plant mixture. Volunteer species, crab grass and bunch grasses, filled the area before reseeding could be performed. Plants were pulled, and it was determined that there was extensive root growth in the subsoil under the biosolids amendments.

The first set of plots yielded the highest biomass for high applications of low and high nitrogen biosolids. High concentrations of soluble zinc and log yard waste did not seem to have any bearing on biomass. It is possible that the subsoil was never used because measurements were taken at the end of the growing season, and so the plant life may have never needed to access moisture in the subsoil. Conventional and special treatments in the second set of plots produced very low levels of biomass while low nitrogen applications had moderate production, and high nitrogen applications had good production.

Plant metals were measured in 1997, 1998, and 1999. The concentration of zinc on the amended soils was similar to normal growing soil. Plant samples on the amended plots indicated that phosphorus levels were within the normal range. Copper and cadmium levels remained similar throughout all years; however, there is one exception. The high nitrogen biosolids and logyard waste plot had a copper deficiency likely due to high pH and lack of organo-copper complexes present earlier in the study.

Table 10. Percent Cover on First Set of Plots in July 1998 and Biomass June1999 (± std dev.)

Application	Rate (mg/ha)	% Cover	Biomass (mg/ha)
Control	N/A	0	0
Low N	55 110	77 93	1.6±1.0 2.5±1.6
High N	55 110	82 93	4.0±1.3 2.8±1.3
High N- log yard	110	95	3.0±1.3

Source: Brown *et al.* (2000), Table 4

5.1.4 Cost

The cost of biosolids used averaged about $35 per wet ton including transportation and application.

5.2 Palmerton

Since 1898 two smelters have produced zinc and other products resulting in 33 million tons of residuals at the Palmerton Superfund site in Carbon County, Pennsylvania. The dumped residuals created a cinder bank 2.5 miles long, 200 feet high, and 1,000 feet wide. The site itself is a 1000-acre plot making it the largest remediation project ever attempted by EPA.

Smelting of concentrated zinc sulfide ores created high emissions of zinc, lead, cadmium, and sulfur dioxide. As a result of the heightened emissions from the East Plant, more than 2000 acres of land lost virtually all vegetation. Metal levels caused a stop in all microbial activity creating a biological wasteland. Trees that had been dead for more than 20 years could not decompose and 30 to 60 cm of topsoil eroded from the site. Based on the levels of contamination at the site, EPA placed Palmerton on the National Priorities List in 1982.

5.2.1 Site Application and Monitoring

In 1988 the Zinc Corporation of America signed an agreement with the EPA to redevelop Blue Mountain by reestablishing grasses followed by trees to approximately 1,000 acres. Conventional revegetation methods had not worked on Blue Mountain in the past because of a unique combination of topographic and chemical factors that exists at the site. Palmerton's Superfund classification made it a candidate for new, more innovative treatments that would have otherwise been unavailable. There were several treatment options to select from including in situ and ex situ. EPA opted for on-site (in situ) treatment for the following reasons:

- Removal of 30 cm of topsoil from the entire site was estimated to cost almost $1.3 billion by EPA;
- Removal of the cinder bank would cost $2.8 billion dollars and require 29 to 45 years to complete; and
- Disposal sites for the removed material would be difficult to find because of the volume of waste.

Most remediation information available (before Palmerton) dealt with heavy metals but without addressing topographic obstacles. After extensive testing with soil amendments and vegetation, the final land application consisted of limestone, potash, biosolids, and fly ash. Because of surface conditions (rocky slopes and tree laden land) the application was blown over the surface and not directly incorporated into the soil. The mixture of biosolids and fly ash was perfectly matched to the site because:

- Handling was improved by the addition of fly ash because biosolids are generally only 15 to 20 percent solids alone;
- Fly ash lightened the color of the dark biosolids reducing soil surface temperatures; and
- Porosity, infiltration, and percolation were increased.

Before application could occur tests were performed on the amendment at the USDA Soil Conservation Service Plant Materials Center. The amendment design, for all compositions, required 2,000 pounds per acre (2,200 kg/ha) of organic nitrogen from biosolids. The ratio of biosolids to fly ash in various blends ranged from 1:1 to 3:1. Almost 10 tons per acre of limestone and 132 pounds per acre of potash were incorporated into all of the amendments. Twelve plants were selected for testing in the Palmerton soil, which was treated with the various biosolids amendments. After a 100 day study, the roots of 11 plants had penetrated the Blue Mountain soil. The most successful of these plants were selected for field-testing.

Researchers arranged ten one-acre plots along an access road on the mid-slope portion of the mountain. Three plots were on the down-slope and seven were uphill in order to test the throwing range of application vehicles. Limestone was applied at double the rate necessary to raise the soil pH to 7.0 in an effort to immobilize heavy metals. An application rate of 21 dry tons per acre of biosolids was used to achieve approximately one ton per acre of organic nitrogen.

After the passage of one growing season the 1:1 biosolids to fly ash ratio produced the highest grass growth while the 3:1 ratio produced the greatest tree growth. In all plots, inorganics seemed to be within tolerable limits including nitrogen, phosphorus, potassium, calcium, and magnesium. Heavy metal concentrations were highest in plants grown in the 3:1 ratio due to the $Ca(OH)_2$ present in the fly ash. Amendments with more fly ash had more $Ca(OH)_2$ available to precipitate heavy metals and make them less phytoavailable.

Initially it proved difficult to obtain materials because companies feared liability for the use of their product. EPA responded by granting suppliers Response Action Contractor status, which absolved them of any federal responsibility when participating in remediation projects except in the case of gross negligence or misconduct. Eventually the state of Pennsylvania granted suppliers the same rights and remediation began in May 1991.

Monitoring equipment from EPA's Office of International Activities was requested during the project but no equipment was granted. However, since the ground water and surface water in the region was classified as severely contaminated from decades of mining activities and beyond hope of recovery, the water monitoring efforts, while of benefit at the site itself, would have had no impact upon the hydrology of the larger area.

Other monitoring techniques at the site included intensive soil sampling conducted both before and after the remediation, measurement of resultant vegetative biomass, analysis of plant tissue, and animal feeding studies.

5.2.2 Performance

Horsehead Industries, Inc., revegetated nearly 1,000 acres of Blue Mountain on the Palmerton site between 1991 and 1995. However, an additional 1,000 acres still require revegetation. In December 1999, EPA issued a Unilateral Administrative Order to current and former owners of the Palmerton site to complete the project. It is expected that Horsehead Industries, Inc., will implement a system to divert surface water around the cinder bank, treat leachate before discharge, and revegetate its surface. The project is expected to take two to three years to complete.

EPA is in the process of completing a feasibility study for the cleanup of soils in the Borough of Palmerton. Well testing performed in late 1998 indicates that a natural cleaning process may be occurring in the aquifer beneath the Palmerton Borough. This natural cleaning process is being further investigated.

A study of the potential effects of the contamination on the ecology of the Palmerton area was due by the spring of 2000. An Ecological Risk Assessment was also presented for review in the summer of 2000. These reports should be finalized and available in the near future. Results of the application are evident when looking at the before and after photographs (seen in the figures section) at the Palmerton site. A graveyard of trees and contaminated soil has been turned into a biologically productive site.

5.2.3 Cost

Horsehead Industries, Inc has conducted the revegetation work performed at the site thus far. They are not required to report their costs to the EPA; however, they have estimated a cost of approximately $10 million in revegetating approx. 1,000 acres of Blue Mountain (C. Root, personal communication).

The former and current owners are performing the biosolids application on the cinder bank. As such, they are under no obligation to provide costs for this project to the EPA (E. Dennis, personal communication).

5.3 Leadville

Mining near Leadville has damaged the ecosystem of the area. High levels of pyrite waste produced by mine tailings have contaminated an eleven-mile stretch of the Arkansas River. A fluctuating water table has resulted in alternating reducing and oxidizing conditions. Oxidation of reduced sulfur has produced highly acidic soil with pH ranging from 1.5 to 4.5. Because of these conditions a metal, salt crust has formed on the soil surface with zinc levels reaching 90 g/kg.

5.3.1 Goals

- Reduce riverbank erosion and degradation
- Provide a vegetative cover for the area
- Evaluate various remediation techniques

5.3.2 Site Application and Monitoring

Full-scale treatments have not been implemented at the Leadville site because researchers are still in the experimental phase of the project. Several plots have been established with varying amendment combinations.

A field experiment was installed in September 1998 to determine if biosolids in combination with limestone could restore a vegetative cover to the tailings deposit (Brown *et al.*, 2000). A randomized plot selection process was used to test the different amendments. Rates of 90 and 180 mg/ha were applied once on the plots as well as biosolids cake and solids from Denver Metro and pellets at 98 percent solids from Boston. Lime was added at 224 mg/ha, materials were incorporated into the top 12 cm of soil, and plots were seeded with annual rye grass in 1999.

Plant and soil samples were collected and analyzed for $Ca(NO_3)_2$ extractable metals and pH. As seen in Table 11 amendments increased the pH and lowered extractable metals within the first fifteen centimeters of soil. These results are expected to continue deeper into the soil as the calcium and magnesium from the lime filter down through the soil.

Two new research areas were installed on the site in July 2000. The first was designed to investigate the amendments that would favor several different native plant communities. Woody materials such as log yard waste were blended with biosolids for testing. The second set of plots investigates which type of liming material will achieve the best short and long-term correction of soil acidity. The movement of lime through the soil profile is also being monitored.

Table 11. Metal and pH Samples Taken after Amendment Application

Amendment	Depth (cm)	pH	Cd	Pb	Zn
Control	0-15	3.9±0.8	11±8	11±3	1200±700
	15-30	4.2±0.7	6±2	18±13	700±200
	30-45	4.9±0.5	5±7	3±3	600±400
Lime	0-15	6.3±0.2	1±1	1.8±0.8	70±100
	15-30	4.4±0.4	5±2	15±0.8	600±300
	30-45	4.9±0.7	5±1	4.3±0.9	500±200
Biosolids only	0-15	4.9±0.2	3±2	14±14	400±200
	15-30	4.8±0.7	6±2	11±5	600±200
	30-45	5.1±0.6	5±5	5±3	500±300
Wet biosolids + lime	0-15	6.4±0.3	0.5±0.4	3±2	30±30
	15-30	5.7±0.5	2±2	2±1	200±200
	30-45	4.7±0.3	6±1	6±3	580±60
Dry biosolids + lime	0-15	6.8±0.3	0.6±0.1	4±3	10±7
	15-30	5.1±0.6	3±2	5±3	400±200
	30-45	4.8±0.5	5±1	5±3	580±70

Source: Brown et al. (2000), Table 4

5.3.3 Performance

The biosolid amendments were effective in establishing a vegetative cover over the areas tested. Since this is not a full-scale project, there are not complete results at this time; however, the results as of now at Leadville are promising. The failure of added limestone to increase soil pH to at least 7.0 suggests use of a more reactive liming material is necessary.

5.3.4 Cost

Currently cost data is not available for the site because full-scale implementation has not occurred.

5.4 Poland – "Project Silesia"

The project, implemented in 1994, took place in the Upper Silesia region of southwestern Poland. The Silesia region is the center for the country's industry and mining. During the communist rein the environment was neglected and large deposits of lead, zinc, and other metals have plagued the area. Waterways became too toxic for aquatic life and emissions of black smog could often be seen in the air. Over 96 million tons of mining wastes were deposited on the site during the 20th Century.

The waste piles, on the site, are spread over several thousand acres and most are phytotoxic preventing revegetation. Without a vegetative cover the piles are highly susceptible to wind and water erosion, which allows metals to enter the environment. Elevated lead levels have been found in children living nearby.

During the last decade many advances, such as the installation of emission scrubbers, have been made to stop additional contamination. However, because of the country's economic situation any remediation technique of the waste piles needed to be inexpensive. This is the reason biosolid remediation came to the forefront as a treatment option. Biosolids are inexpensive and were available locally because of increased waste production in preceding years.

5.4.1 Goals

- Determine suitability of local biosolids for reclamation purposes;
- Develop an inexpensive method for incorporating biosolids into highly contaminated topsoil;
- Develop rules for topsoil modification and vegetation selection;
- Set standard for monitoring surface water and ground water contamination; and
- Train officials, local authorities, and interested enterprises to use biosolids appropriately to protect public health and the environment.

5.4.2 Site Application and Monitoring

The project team selected to study the use of biosolids on the Silesia site consisted of EPA, USDA, and Virginia Tech along with Polish scientists from the Institute of Soil and Plant Cultivation and the Center for Research and Control of the Environment. Biosolid use at the Superfund site in Palmerton, Pennsylvania, served as a basis for application in Silesia.

All legal aspects in relation to biosolids application were analyzed at the initial stage of project implementation, resulting in the following:

1. There was a possibility of no legal restrictions on biosolids use for remediation.

2. Obtaining a commercial biosolids permit was complicated and required the approval of the Provincial Sanitary and Epidemiological Station, State Environmental Inspector, and the provincial authorities.

3. The area produced the necessary sludge needed to form biosolids and production was expected to double in upcoming years, keeping costs low.

Non-ferrous smelter tailings and mine spoils were selected for testing because of their differing characteristics. Mine spoils are a problem because of the large areas in need of reclamation; however, reclamation of this type of waste does not require additional treatment after application. Therefore, large volumes of biosolids can be utilized with relative ease. On the other hand, treatment of smelter waste varies greatly because its comparatively smaller area in need of reclamation. Despite its smaller area, smelter waste is more difficult to treat because of hazardous metal concentrations. More soil modification and flora selection is necessary to be successful in remediation.

The experimental site for mine waste was 0.6 hectares and located in Ruda Slaska. The site was divided into to parts 0.3 ha each with one side receiving application and the other left as a control. Digested and dried biosolids were applied at rates of 75 tons of dry mass/ha and 150 tons of dry mass/ha and mixed within the first 20 cm of the waste. The fields were then sown with various grass species.

The lead/zinc waste pile in Piekary Slaskie was selected for reclamation to test biosolids effects on smelter waste. The tailings consisted of smelter wastes from a Doerschel furnace and a Welz smelting process. An environmental assessment revealed that the two wastes were mixed to a great extent. Before application soil samples were taken from the soil from over 160 grid points and analyzed for pH, cadmium, zinc, lead, sodium, sulfate, and electrical conductivity (Table 12). Calcium carbonate and calcium oxide were added to reduce phytotoxicity and metal solubility. The loading rate for the Welz process waste was 5 tons of calcium carbonate and 1.5 tons of calcium oxide per hectare. Doerschel loading rates were 30 tons of calcium carbonate and 5 tons of calcium oxide per hectare. Next, biosolids were applied by immediate incorporation to a depth of 20 cm at rates of 150 and 300 dry tons per hectare. Two grass mixes were planted on the amended sites in early October.

Table 12. Metal Concentrations of Waste Samples Before and After Biosolids

Waste	Time	Zn (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	pH
Welz	Before application	343	17.6	1.8	7.0
	After Application	279	17.7	1.1	7.2
Doerschel	Before application	1670	108	5.4	5.8
	After Application	983	57.4	2.9	6.0

Source: U.S. EPA, 2000

5.4.3 Performance

The sites with mine spoil contamination yielded good results after biosolid application. Both loading rates produced good reclamation results. Grass coverage was uniform and grass selection was visible as some species were eliminated over time.

Even though the Welz waste area had high levels of water-soluble metals, vegetation was established on 85 percent of the surface in 1995. Plant roots present in the Welz waste penetrated the tailings 10 to 20 cm and legumes and native species began to grow on the site in 1996. This was a validation of the hypothesis that biosolids could support long-term plant growth. Heavy metals were present in vegetation, however, they stabilized over time and a study revealed their metal content had no effect on cattle grazing in the area.

On the other hand, the Doerschel area had established no vegetation. Sampling in 1995 indicated high concentrations of soluble zinc and cadmium compounds as well as sulfates in the topsoil. The lack of vegetation was likely due to the high salinity and elevated levels of soluble zinc and cadmium. Calcium carbonate and calcium oxide did not prove effective in raising pH and reducing metal mobility. Further experiments revealed that calcium carbonate did little if anything no matter that amount applied. Calcium oxide proved effective in reducing pH and metal movement in the laboratory; however, the results from the field study indicate that this effect is only temporary.

Another treatment was carried on the Doerschel waste in 1995. The treatment involved the application of a 10-20 cm lime cap (CaO and $CaCO_3$) on the surface of the tailings, and the application of an additional 300 tons of dry mass biosolids. The biosolids were incorporated into the cap with the aid of chisel plow and seeded with the same mixture used initially.

The result was the establishment of a 75-80% vegetative cover by the spring of 1996. There was also a great reduction in the amount of metal toxicity. However, plant roots only penetrated the first 2 cm of the Doerschel waste material indicating a diminished ability for plants to withstand a summer drought.

5.4.4 Cost

Because of funding limitations remediation costs had to be kept relatively low. The estimated cost of implementation is almost impossible to determine given the differences in Poland's economy and that of the United States (e.g., salaries). (Personal Communication Kenneth Pantuck) The following are major differences that make comparison to U.S. projects difficult:

- Labor costs vary so much between Poland and the US. For instance, the monthly salary of an average worker is about $200-300;
- The Poles relied more on hand labor than would a comparable U.S. site;
- The waste lime that was used was available nearby these sites at no cost; and
- Truck transportation costs were a much more important factor.

Based on these factors, no cost data related to the Silesia site will be presented in this report because of its irrelevancy to U.S. sites.

Figure 3 – Bunker Hill Plot Before Treatment

Figure 4 – Bunker Hill Plot After Treatment

Figure 5 – Palmerton Superfund Site Before Treatment

Figure 6 – Typical Conditions on Blue Mountain After Biosolids Application

Figure 7 – Upper Arkansas River at Leadville

Figure 8 – Test Plots at Leadville Site

Appendix A – EPA Regional Biosolids Contacts

Region	States and Territories	Contact
1	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	Thelma Hamilton Ph: (617) 565-3569 Fax: (617) 565-4940
2	New Jersey, New York, Puerto Rico, Virgin Islands	Alia Roufaeal Ph: (212) 263-3864 Fax: (212) 264-9597
3	Delaware, Maryland, Pennsylvania, Virginia, West Virginia	Ann Carkhuff Ph: (215) 814-5735 Fax: (215) 597-3359
4	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee	Vince Miller Ph: (404) 347-3012 ext. 2953 Fax: (404) 347-1739
5	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	Ash Sajjad Ph: (312) 886-6112 Fax: (312) 886-7804
6	Arkansas, Louisiana, New Mexico, Oklahoma, Texas	Stephanie Kordzi Ph: (214) 665-7520 Fax: (214) 665-6490
7	Iowa, Kansas, Missouri, Nebraska	John Dunn Ph: (913) 551-7594 Fax: (913) 551-7765
8	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming	Bob Brobst Ph: (303) 312-6129 Fax: (303) 294-1386
9	Arizona, California, Hawaii, Nevada, American Samoa, Guam	Lauren Fondahl Ph: (415) 744-1909 Fax: (415) 744-1235
10	Alaska, Idaho, Oregon, Washington	Dick Hetherington Ph: (206) 553-1941 Fax: (206) 553-1775

Appendix B – State Biosolids Contacts

State	Contact	State	Contact
Alabama	Cliff Evans (205) 271-7816	Montana	Pat Burke (406) 444-7343
Alaska	Bill Fagan (907) 465-5142	Nebraska	Rick Bay (402) 471-4200
Arizona	Melanie Barton (602) 207-4319	Nevada	Mahmood Azad (702) 687-4670 x3141
Arkansas	Daniel Clanton (501) 570-2826	New Hampshire	Selena Makofsky (603) 271-3398
California	Mark Bradley (916) 255-2931	New Jersey	Mary Jo Aiello (609) 633-3823
Colorado	Phil Hegeman (303) 692-3598	New Mexico	Arun Dhawan (505) 827-2809
Connecticut	Bob Norwood (203) 424-3746	New York	Sally Rowland (518) 457-7336
Delaware	Ron Graeber (302) 739-4761	North Carolina	Dennis Ramsey (919) 733-5083
District of Columbia	Ronald Eng (202) 404-1120	North Dakota	Gary Bracht (701) 221-5210
Florida	Juliene Gissendanneer (904) 488-4525	Ohio	David Jensuk (614) 644-2021
Georgia	Nancy Prock (404) 362-2680	Oklahoma	Danny Hodges (405) 271-7362 x127
Hawaii	Dennis Tulang (808) 586-4294	Oregon	Mark Ronayne (503) 229-5279
Idaho	Jerry Yodder (208) 334-5856	Pennsylvania	Steve Socash (717) 787-7381
Illinois	Alan Keller (217) 782-0610	Rhode Island	David Chopy (401) 277-3961
Indiana	Dennis Lassiter (317) 232-8732	South Carolina	Michael Montebello (803) 734-5300
Iowa	Billy Chen (515) 281-4305	South Dakota	Bill Geyer (605) 773-3351
Kansas	Ed Dillingham (913) 296-5513	Tennessee	John McCurran (615) 532-0625
Kentucky	Art Curtis (502) 564-4310	Texas	Stephen Bell (512) 463-8491
Louisiana	J. Kilren Vidrine (504) 564-6716	Utah	Lisa Rogers (801) 538-6146

Maine	David Wright (207) 287-2651	Vermont	Katie Gehr (802) 241-3822
Maryland	Simin Tigari (410) 631-3375	Virginia	Cal Sawyer (804) 241-3822
Massachusetts	Dennis Dunn (617) 556-1130	Washington	Kyle Dorsey (206) 459-6356
Michigan	Barry Burns (517) 335-3301	West Virginia	Clifton Browning (304) 558-2108
Minnesota	Jorja DuFresne (612) 296-9292	Wisconsin	Greg Kester (608) 267-7611
Mississippi	Glen Odom (601) 961-5171	Wyoming	Larry Robinson (307) 777-7075
Missouri	Ken Arnold (314) 751-6825		

Appendix C – Laws Affecting Biosolids

Federal Water Pollution Control Act 1972: Deals with the restoration and maintenance of the chemical, physical, and biological integrity of U.S. waters. The law authorizes the planning, design, and construction of publicly owned wastewater treatment works by the federal government. It also issued sludge management guidelines and regulations including pretreatment standards for industrial waste sent to POTWs. It developed area-wide management plans including best management practices.

Solid Waste Disposal Act 1976: Deals with the regulations of solid waste management practices to protect human health and the environment while promoting the conservation and recovery of resources forms solid wastes. Technical and financial assistance, training grants, solid waste planning, and hazardous waste regulatory programs are also included in the law. The key aspect is the comprehensive regulatory system to ensure the proper management of hazardous wastes.

Clean Air Act Amendments 1970 and 1977: Deals with the protection and enhancement of the quality of U.S. air resources to protect public health and the environment. Research and development, technical and financial assistance, emission standards, and air quality planning are included in the law. It controls hazardous air pollutants and ensures new source performance standards.

Marine Protection, Research, and Sanctuaries Act 1972: Regulates the dumping of all types of materials into ocean waters and limits the ocean dumping of materials that would adversely affect human health and the marine environment. It prohibits ocean dumping and transportation of materials from the U.S. to be dumped except under permit. A 1977 amendment (PL 94-469) effective on December 31, 1981, terminated ocean dumping of sewage sludges defined as municipal waste. A similar amendment was enacted in 1980 regarding industrial wastes.

Toxic Substances Control Act 1976: Provides for testing and notification of chemical substances, which present an unreasonable risk or injury to health or the environment. EPA is required to coordinate action taken under the act with actions taken under other federal laws. The EPA is also required to issue rules respecting the manufacturing, processing, commercial distribution, and disposal of polychlorinated biphenyls.

Source: Robert K. Bastian

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